Potential carbon mitigation by Wori mangrove forest, North Sulawesi, Indonesia

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Abstract. Mangrove forests play an important role in global carbon storage to mitigate excessive carbon dioxide (CO_2) through huge and long-term storage capacity in its tree, leaves, roots and sediment. This study aims to estimate potential C mitigation by Wori Regency mangrove forests. This study was focused on potential C mitigation by mangrove trees and litter biomass. Data were collected using the line-transect method. Tree biomass was determined from established 10x10 m plots. Mangrove litter samples were collected using a litter trap, for 28 days. Estimation of mangrove tree biomass was calculated using an allometric formula. Results showed that average carbon storage by mangrove tree biomass, C and CO_2 were 429 t ha^{-1}, 201.63 t C ha^{-1}, and 739.98 t CO_2 ha^{-1}, respectively, while litter biomass, C and CO_2 were 6.76 t ha^{-1}, 3.18 t C ha^{-1} and 11.65 t CO_2 ha^{-1}, respectively. The potential of total average biomass, C, and CO_2 in Wori mangrove forest were 435.76 t ha^{-1}, 204 t C ha^{-1} and 751.64 t CO_2 ha^{-1}, respectively. By this robust-field carbon measurement results, potential carbon mitigation was indicated by mapping the contribution of mangrove forests at district level, which could further contribute to global carbon budget data.

Key Words: biomass, carbon measurement, carbon storage, estimation.

Introduction. Rising carbon dioxide (CO_2) emission is occurring. Actions such as maintaining and improving the ability of CO_2 assimilation and storage are a crucial aspect of climate change mitigation. It was recognized that the role of coastal ecosystems (mangrove, salt marsh, seagrass, etc.) in climate change is mitigation, as well as adaptation. Mangrove forests provide multiple ecosystem services for the surrounding environment as well as for the coastal communities, such as blue carbon sequestration, storm protection, nursery area for water organisms, buffer against hydrodynamic energy, fuel as wood, charcoal, etc. (Walters et al 2008; Donato et al 2011; Miteva et al 2015; Barbier 2016). Coastal blue carbon ecosystems can act as important CO_2 sequestration areas while providing food, fuel, raw materials and numerous other advantages. Mangrove, saltmarsh and seagrass are coastal blue carbon ecosystems because of their services in carbon mitigation (Mcleod et al 2011; Mudiyarso et al 2015) through photosynthesis processes, which absorb and store carbon in above and below-ground biomass (Nelleman et al 2009).

As the largest mangrove forest area in the world, the potential of the Indonesian coastal natural resources is diverse and large. According to data provided by the National Statistics Institution (BPS 2017), the total area covered the by coastal blue carbon ecosystem in Indonesia in 2016 was $3.9x10^{-7}$ ha of mangroves and $5.6x10^{-6}$ ha of seagrass. Mangrove forests can be found in all Indonesian provinces (34 provinces), with Papua Province having the largest area cover ($1.1x10^{-7}$ ha), and Yogyakarta Province the smallest mangrove area cover ($0.00004x10^{-7}$ ha). With such a massive area of mangrove coverage, Indonesia has a big role in carbon mitigation. In North Sulawesi province, the mangrove forest covers 11546 ha, 857 ha (7.42%) of dense forest and 10689 ha (92.58%) of moderate forest (BPDAS Tondano 2011). Wori Regency is one of the North Sulawesi regencies that have mangrove forests in good condition. A dense and extensive area of mangrove forests can be found here. Even though it has a high coverage rate of mangrove forests, there are limited studies conducted on the potential for carbon mitigation by the mangrove area (Sondak 2015; Verysandria et al 2018; Bachmid et al 2018; Tidore et al 2018). Coastal blue carbon ecosystems have become one of the most threatening ecosystems in the world, because the annual losses of world mangrove forest, seagrass and salt marsh have reached their critical points of 67%, 35% and 29%, respectively (Murray et al 2011; Pendleton et al 2012). There are direct and indirect threats to mangroves in Indonesia (Purnobasuki 2012). Indirect threats included the development of coastal areas (aquaculture, agriculture, harbor and housing), whereas direct threats were caused by household pollution and careless management of river basins. Wori district faces some factors that could cause a loss of mangrove services, since this area is known as one of the local tourist destinations. One of the services that could be lost is the mangrove role in carbon mitigation. When mangrove forests are cleared, they will lose their function as carbon absorbers and the carbon stored in biomass and sediment will be released into the atmosphere (Pendleton et al 2012; Kauffman et al 2014). No data is available for mapping the storage capacity of carbon by mangrove forests at district level in North Sulawesi Province. The purpose of this study is to estimate the potential carbon (C) mitigation by mangrove trees and litter in the Wori area.

Material and Method

Description of the study sites. The study was carried out in Wori mangrove forest from July to October 2020. Wori mangrove forest is located on the coast of North Sulawesi Peninsula (1°42’0”N - 1°36’0”N and 124°50’0”E - 124°56’0”E). The map of the study location is presented in Figure 1.

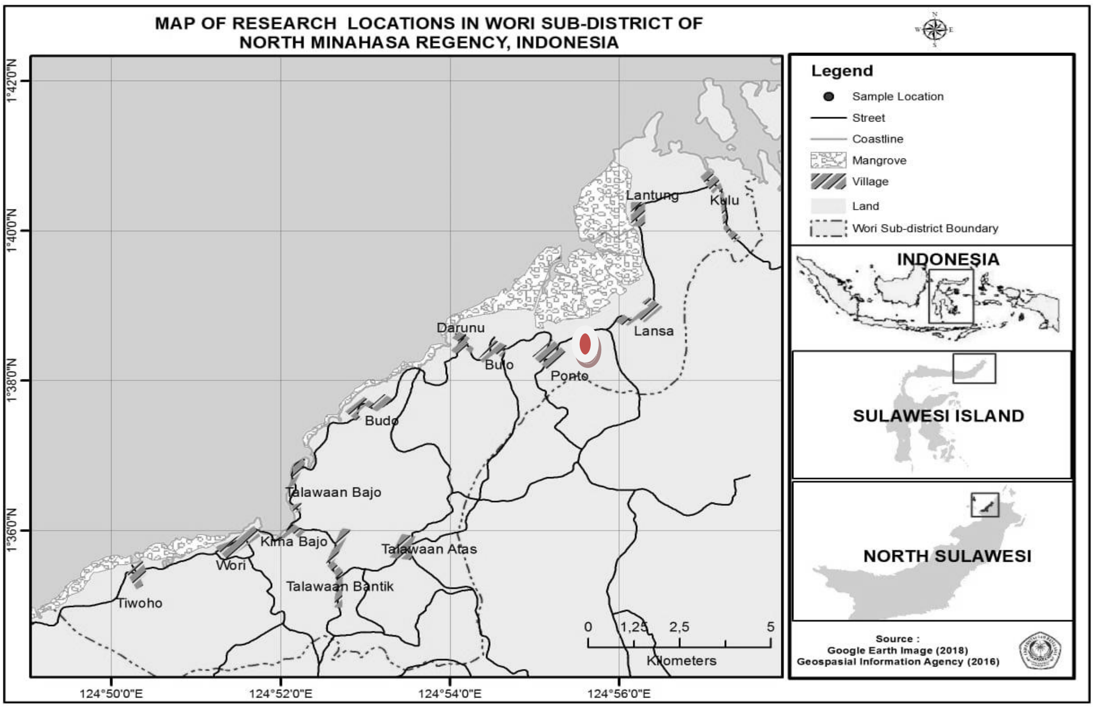

Figure 1. Map of North Sulawesi and Wori mangrove forest (red circles represent study areas: Ponto village, Lansa village, and Lantung village).

Data collection. Mangrove tree biomass data were collected using line-transect quadrat method in three villages as point collections (Ponto, Lansa and Lantung). There were four stations in each location, with three line transects for each station. Tree biomass was collected from established 10x10 m plots. The plots were laid along the 100 m transects from the sea perpendicular to the coastline. The total of trees within quadrats was determined, trees were identified, and their diameter at chest height (dch) was measured. Chest height was considered at 1.3 m. Mangrove litter samples were collected using a litter trap (1x1 m^2) made from a net (0.2 cm mesh size). Traps were randomly placed within the plots, approximately 1.5 m above the ground under the mangrove canopy. Litter traps were placed for 28 days and the data were collected every week. After all the litter samples were collected, they were transported to the center laboratory of Sam Ratulangi University to be weighed for their fresh weight and later dried at 80°C for 48 hours. Dry mass was weighted afterward (Mahmudi et al 2008).

Carbon measurement. The estimation of mangrove tree biomass data was calculated using an allometric formula developed by Komiyama et al (2005). As there was no specific information about the wood density of mangroves species in the study location, we quantified the wood density value using the methods used by Komiyama et al (2005). Carbon content in mangroves was estimated using the method mentioned by IPPC (2006), based on tree biomass (above-ground biomass), while C concentration in organic matter was considered 0.47 (47%) (IPPC 2006). Carbon content in mangrove trees was then estimated by multiplying 0.47 with the above-ground biomass. The potential amount of CO_2 that could be sequestered was calculated by multiplying C by the amount of CO_2 in 1 g of dry plant material, which is 3.67 (Howard et al 2014). Litter biomass was estimated by dividing the dried weight (dw) in plots by wet weight (ww) of plots and then multiplying the result by the total wet weight (Hairiah et al 2011).

Data analysis. Above-ground biomass was calculated by multiplying wood density with an allometric equation and tree dch.

$W_{top} = \rho * 0.251 dch^{2.46}$ (Komiyama et al 2005)

Where: W_{top} is the above-ground biomass; ρ is the wood density; and dch is the diameter at chest height (1.3 m).

Carbon content in mangrove trees was estimated by multiplying 0.47 to above-ground biomass, with the formula:

$C_{con} = 0.47 \times B$ (IPPC 2006)

Where: C_{con} is C concentration, and B is biomass.

The potential amount of CO_2 that could be sequestered was calculated with the following formula:

$WCO_2 = C \times 3.67$ (Howard et al 2014)

Where: WCO_2 is CO_2 potential sequestration; C is carbon concentration; and 3.67 is the amount of CO_2 in 1 g of dry plant material.

Mangrove litter biomass was calculated using the formula used by Hairiah et al (2011):

$DW_t=(DW_p/WW_p) \times WW_t$

Where: DW_t is the total dry weight; DW_p is the dry weight per plot; WW_p is the wet weight per plot; and WW_t is the total wet weight.

Results and Discussion. Wori mangrove forest is located in the Wori district, North Minahasa Regency, North Sulawesi Province. The mangrove forest in the study area has natural mangrove stands. Overall, in our study location, we found four mangrove species: *Rhizophora mucronata*, *Sonneratia alba*, *Avicennia marina* and *Xylocarpus granatum* (Table 1). Generally, *R. mucronata* was the most abundant mangrove species in the study area. *X. granatum* was only found in Ponto village.

Table 1

Mangrove species on study site

Species	Local name	Common name
Avicennia marina	Api api	Grey mangrove
Rhizophora mucronata	Lolaro	Stilt mangrove
Xylocarpus granatum	Kira-kira	Cannonball mangrove
Sonneratia alba	Posi-posi	Apple mangrove

Table 2 illustrates mangrove species biomass, C and CO_2 content in the present study. *R. mucronata* have the highest total biomass, C and CO_2 of all species found in all study sites, whilst *X. granatum* have the lowest. The highest values for biomass, C and CO_2, were observed for *R. mucronata* in Lansa, being 260 t ha^{-1}, 122.20 t C h^{-1}, and 448.47 t CO_2 h^{-1}, respectively. *X. granatum* had the lowest values (34 t ha^{-1}, 15.98 t C h^{-1}, 58.65 t CO_2 h^{-1}) because it was found in only one study area. Total biomass, C and CO_2 in the study site were 1287 t h^{-1}, 604.89 t C h^{-1}, and 2,219.95 t CO_2 h^{-1}, respectively, with an average of 321.75 t h^{-1}, 151.22 t C h^{-1}, and 554.99 t CO_2 h^{-1}.

Total mangrove litter biomass, C and CO_2 value are presented in Table 3. The total biomass was 1.79 t ha^{-1}, 15.72 t ha^{-1} and 2.76 t ha^{-1} in Ponto, Lansa and Lantung, respectively. The highest C and CO_2 values were found in station 3 in Lansa (3.14 t C ha^{-1} and 11.54 t CO_2 h^{-1}) while the lowest were found in Ponto station 4 (0.08 t C ha^{-1} and 0.31 t CO_2 h^{-1}). Overall, total litter biomass, C and CO_2 were 20.27 t h^{-1}, 9.53 t C h^{-1} and 34.96.65 t CO_2 h^{-1}, with the average of 6.76 t h^{-1}, 3.18 t C h^{-1}, and 11.65 t CO_2 h^{-1}.

Mangrove tree and litter biomass, C, and CO_2 are presented in Table 4. Total mangrove tree biomass in the study area was 1287 t ha^{-1}, with an average of 429 t ha^{-1}. The highest biomass was found in Lansa village (706 t ha^{-1}), followed by Lantung (315 t ha^{-1}) and Ponto (266 t ha^{-1}). C and CO_2 content indicate a similar pattern to the biomass, where Lansa has a total of 331.82 t C ha^{-1} (1217.78 t CO_2 ha^{-1}), Lantung 148.05 t C h^{-1} (543.34 t CO_2 ha^{-1}), and Ponto 125.02 t C ha^{-1} (458.82 t CO_2 h^{-1}). Lansa has the highest litter biomass, C and CO_2 among study sites, with 15.72 t h^{-1}, 7.39 t C ha^{-1} and 27.12 t CO_2 h^{-1}, respectively. It is followed by Lantung, with 2.76 t ha^{-1}, 1.30 t C h^{-1}, 4.76 t CO_2 h^{-1}, respectively, and Ponto with 1.79 t h^{-1}, 0.84 t C h^{-1}, 3.09 t CO_2 h^{-1}, respectively. The average biomass, C and CO_2 were 6.76 t h^{-1}, 3.18 t C h^{-1}, and 11.65 t CO_2 h^{-1}, respectively.

Four mangrove species (*R. mucronata*, *S. alba*, *A. marina* and *X. granatum*) were found in the present study. This result is supported by several previous studies nearby the study area such as Bunaken National Park, Mantehage Island, Tiwoho, Kuala Batu, Tongkaina, Darunu and Budo mangrove forests (Kaunang & Kimbal 2009; Tabba et al 2015; Anthoni et al 2017; Sapsuha et al 2018; Bachmid et al 2018; Sondak et al 2019; Upara et al 2021; Tidore et al 2021). The presence of mangrove forests in this area is crucial to support adjacent ecosystems and human life. Therefore, keeping the mangroves in a natural good condition is very important.

This study found that the biomass of mangrove trees varied in accordance to the coverage area. Thus, Lansa village had a higher net biomass production compared to Ponto and Lantung villages. According to Kusmana (2002), the mangrove net biomass production value ranging from 62.9–398.8 t h^{-1} can be categorized in the "good contribution production" category. The value in our study exceeded these ranges (429 t ha^{-1}), meaning that the above ground mangrove forest in this area is dense. Compared to other areas in the North Sulawesi Province and Indonesia, this study also showed higher biomass than the findings of Dharmawan & Siregar (2008), Windarni et al (2018), Bismark et al (2008), Murdiyaso et al (2009), Suryono et al (2018), which ranged from 49.13 to 431.78 t ha^{-1}. In contrast, our result was comparable to those found in Bawoho Mangrove Forest and Palawan Mangrove Forest, Philippines (Abino et al 2014; Bachmid et al 2018), where total biomass ranged from 433 to 561.2 t ha^{-1}.

Table 2

Mangrove species biomass, carbon and carbon dioxide content

Species	*Ponto (t ha^{-1})*			*Lansa (t ha^{-1})*			*Lantung (t ha^{-1})*				*Total (t ha^{-1})*	*Total (t ha^{-1})*
	B	*C*	*CO_2*	*B*	*C*	*CO_2*	*B*	*C*	*CO_2*	*B*	*C*	*CO_2*
Rm	121	56.87	208.71	260	122.2	448.47	101	47.47	174.21	482	226.54	831.39
Am	95	44.65	163.87	206	96.82	355.33	35	15.51	56.92	334	156.98	576.12
Sa	16	7.52	27.60	240	112.80	413.98	181	85.07	312.21	437	205.39	753.79
Xg	34	15.98	58.65	-	-	-	-	-	-	34	15.98	58.65
Total	266	125.02	458.83	706	331.82	1217.78	315	148.05	543.34	1287	604.89	2219.95
Average	66.50	31.26	114.71	235.33	110.61	405.93	105	49.35	181.11	321.75	151.22	554.99

Note: Rm - *Rhizophora mucronata*; Am - *Avicennia marina*; Sa - *Sonneratia alba*; Xg - *Xylocarpus granatum*; B - biomass.

Table 3

Mangrove litter biomass, carbon and carbon dioxide content

Location	*Station 1 (t ha^{-1})*			*Station 2 (t ha^{-1})*			*Station 3 (t ha^{-1})*			*Station 4 (t ha^{-1})*			*Total (t ha^{-1})*		
	B	*C*	*CO_2*	*B*	*C*	*CO_2*	*B*	*C*	*CO_2*	*B*	*C*	*CO_2*	*B_{tot}*	*C_{tot}*	*CO_{2tot}*
Ponto	0.82	0.39	1.41	0.57	0.27	0.98	0.22	0.10	0.38	0.18	0.08	0.31	1.79	0.84	3.09
Lansa	0.29	0.14	0.51	4.50	2.12	7.76	6.69	3.14	11.54	4.24	1.99	7.31	15.72	7.39	27.12
Lantung	1.05	0.49	1.81	0.56	0.26	0.97	0.68	0.32	1.17	0.47	0.22	0.81	2.76	1.30	4.76
Total	2.16	1.02	3.73	5.63	2.65	9.71	7.59	3.57	13.09	4.89	2.30	8.43	20.27	9.53	34.96
Average	0.72	0.34	1.24	1.88	0.88	3.24	2.53	1.19	4.36	1.63	0.77	2.81	6.76	3.18	11.65

Table 4

Mangrove tree and litter biomass, carbon and carbon dioxide

Location	*Tree (t ha^{-1})*			*Litter (t ha^{-1})*			*Total (t ha^{-1})*		
	B	*C*	*CO_2*	*B*	*C*	*CO_2*	*B*	*C*	*CO_2*
Ponto	266	125.02	458.82	1.79	0.84	3.09	267.79	125.86	461.91
Lansa	706	331.82	1217.78	15.72	7.39	27.12	721.72	339.21	1244.89
Lantung	315	148.05	543.34	2.76	1.30	4.76	317.76	149.35	548.10
Total	1,287	604.89	2219.95	20.27	9.53	34.96	1307.27	614.42	2254.91
Average	429	201.63	739.98	6.76	3.18	11.65	435.76	204.81	751.64

Note: B - biomass.

There are some factors that could affect the amount of mangrove tree biomass, such as age, dominant species and locality (Komiyama et al 2008). Since the mangrove trees in the study area are well established and the estimated average of their age is more than

20 years, this can be assumed as one of the factors that influence high biomass production. In addition, a tree's age is also important for C store (Estrada & Soares 2017). An increase in the age of mangroves will be followed by an increase in carbon sequestration potential (Sahu & Kathiresan 2019). Tree height is one of the factors that can contribute to mangroves above ground C stocks (Kauffman et al 2020). Other factors such as tree density, species composition, growth forms, and stem diameter are also playing important role in determining biomass (Lugo & Snedaker 1974; Woodroffe 1985; Estrada & Soares 2017; Vinod et al 2018). Biomass production has a positive correlation with tree height and diameter (Adinugroho 2006; Kairo et al 2008) and is exponentially correlated with tree stem diameter, but inversely proportional with tree density (Bai et al 2021).

Mangroves can help combat climate change and act as a long-term carbon sink (Howard et al 2017). Carbon uptake by mangroves is accumulated in tree biomass before being lost in the decomposition process and exported to nearby ecosystems (Alongi 2014). Carbon in plant biomass including mangrove biomass can be stored for years to decades (Mcleod et al 2011). Based on the amount of biomass produced by mangrove trees and litter, our results on average C and CO_2 content in tree biomass are comparable to those of previous studies. Imiliyana et al (2012), in Sampang Madura, found a total of 344.5 t C ha^{-1} in species *R. stylosa* stem. Windarni et al (2018) estimated that mangrove trees can store 197.36 t C ha^{-1}, while litter can store 1.25 t C ha^{-1} for *R. stylosa*. 182.5 t C h^{-1} and 669 t C ha^{-1} were stored by *A. marina* in Ciasem mangrove forest (Dharmawan & Siregar 2008). 263.8 t C ha^{-1} and 1944.5 t CO_2 were found in Palawan, Philippine mangrove forest (Abino et al 2014). Carbon content in above-ground biomass in Perancak mangrove forest was 86.11 t C ha^{-1} (Suryono et al 2018), 48.12 t C in Pintu Kota mangrove forest (Tiolong et al 2019), and, in Kuala Batu, mangrove forest was 37.62 t C ha^{-1} (Bachmid et al 2020). Mangrove biomass is correlated to carbon content, with a high biomass value leading to a high C value. This statement is demonstrated in many studies on C content in mangrove biomass (Dharmawan & Siregar 2008; Bismark et al 2008; Imliyana et al 2011).

Carbon stored in mangrove forests is higher than in any other forests (Kauffman & Donato 2012). Globally, the mean C stocks in mangroves was estimated to be 885 t C ha^{-1}. Mangrove forests in West-Central Africa contribute with 799 Mg C ha^{-1} stored, while Latin America and Asia with 940 Mg C ha^{-1}, and 1049 Mg C ha^{-1}, respectively (Kauffman & Bhomia 2017). Southeast Asia C stocks range between 332-2205 t C ha^{-1} (Alongi 2012). Donato et al (2011) stated that, in the Indo Pacific Region, mangrove carbon stock is doubled compared to tropical forests. The condition of mangrove forests in the study area is considered good due to protection efforts by the local government (conservation regulation) and support by local communities. With regulation and support, the functionality of mangrove forests in this area as carbon storage has continued.

Leaf litter was the dominant type of litter during the study period. An average of 6.76 t h^{-1} of litter biomass production indicated that the mangrove forest in the study area has potential for carbon mitigation. Kusmana (1993) indicated that the range of mangrove forest litter production was between 5.7 and 25.7 t h^{-1} y^{-1}., which means our result of litter biomass production shows the potential of carbon mitigation, being within the mentioned range. Moreover, the average mangrove litter C in our study was 3.18 t C ha^{-1}, which was higher than in a study by Windarni et al (2018) at 1.25 t C ha^{-1}, and by Imiliyana et al (2012) at 0.080 t C ha^{-1}. Litter production and mangrove tree density are among the factors that stimulate C storage in mangrove leaf litter (Hidayanto et al 2004; Rosita et al 2013). Wind and rain were among the factors that influence litter production, with higher rainfall contributing to higher litter production (Torres et al 2018). This explains why litter production was high in our study area, particularly in the first 20 days of our study, due to regularly experiencing heavy rain and strong wind. In addition, litter production is influenced by mangrove density, so mangrove forests with high density can produce more litter than those with low density (Sopana 2013; Andrianto et al 2015; Widhitama et al 2016).

Conclusions. The Wori mangrove forest has a big contribution to supporting carbon mitigation. Higher amounts of biomass were found for tree biomass than for litter biomass. The highest biomass, carbon and carbon dioxide content were found in the Lansa mangrove forest. The estimation of carbon potential could suggest that managing mangrove forest ecosystem services as carbon stores toward potential CO_2 sequestration with the aim of mitigating climate change should be a priority. More assessments and a wider coverage area are important in a future study to get the whole potential of C mitigation by mangrove forests in North Sulawesi.

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Conflict of Interest. The authors declare that there is no conflict of interest.

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